Ph.D. SYNOPSIS

Geochemistry and Petrogenesis of the Chimalpahad Archaean Anorthosite Layered Complex, South India: Implications for Mantle Sources and Magma Chamber Processes

ABSTRACT

Archaean Layered Anorthosite Complexes are rare plagioclase-rich cumulate rocks restricted to the Archaean times. In spite of extensive studies, both the parental liquids and the emplacement tectonic setting of Archaean anorthosites are still enigmatic. Both basaltic, picritic and even komatiitic are proposed to be liquids parental to the Archaean anorthosites; a variety of tectonic settings are proposed for their emplacement including analogs to the modern style continental arc and island arc tectonic settings. The Archaean anorthosite episode is generally considered to represent large scale mantle melting, oceanic crust recycling and definite advent of horizontal tectonics. Knowledge of the origin and tectonic setting of Archaean anorthosites is thus fundamental to our understanding of development of mantle sources through subduction processes, Archaean tectonics, hydrous magma generation and oceanic crust recycling.

The present study focuses on a rare Archaean Layered Anorthosite Complex occurring in and around Chimalpahad area within the Nellore Schist Belt, Andhra Pradesh to understand its petrogenesis and tectonic setting. Geochemical fingerprinting of the processes including mantle sources, conditions of melting, evolution of melts parental to Chimalpahad anorthosite cumulates will be addressed in the present work. The objective of the present study is decipher the mantle source composition, composition of parental liquids, and parental magma evolution within the magma chamber to form the ultramafic, mafic and anorthosite cumulates, tectonic environment of original emplacement of Chimalpahad Archaean Layered Anorthosite Complex. This will help in deciphering the nature of mantle source composition, sub-volcanic magma chamber processes and evaluate the certainty of plate-like processes in Archaean times. Detailed filed studies including sampling of all the lithounits, comprehensive petrographic studies and

geochemical and mineral-chemical analyses for major, trace and rare earth elements for a large number of samples will be the methodology we adopt to achieve the objectives of the study.

Keywords: Archaean Layered Anorthosite, Chimalpahad, Nellore Schist Belt, South India, Parental Liquids, Magma Chamber Processes, Tectonic Setting, Petrogenesis, Geochemistry.

INTRODUCTION

Archaean Layered Anorthosite Complexes represent unique geological phenomenon in the early history of planet Earth. The complexes contain minor ultramafic rocks, and dominant anorthosites and leucogabbros. High anorthite content of plagioclase (An > 90% in some cases) is very characteristic of these layered complexes, which is known only from the anorthosites of Moon and not repeated in later Earth's history. The Archaean Layered Complexes occur as sheets within the greenstone belts and contain chromium- and PGE-bearing minerals. The origin of the Archaean Layered Anorthosite Complexes is highly debated and a challenge to the geologists and is yet to be resolved. Deciphering the parental liquid compositions, comprehending the magma chamber processes and evaluating the tectonic environment of their emplacement are contentious issues in the Precambrian geology. The restriction of these high-An anorthosites to the Archaean suggests changing mantle sources or thermal regimes with time. Therefore, resolving the origin of the Archaean Anorthosite Complexes is not only relevant in terms of petrology and tectonics but helps in understanding the spatio-temporal evolution of mantle sources and thermal regimes.

GEOLOGY OF THE AREA

The 600 km long west-vergent NKSB – comprising of the Nellore Schist Belt (NSB) in the south and the Khammam Schist Belt (KSB) in the north – is sandwiched between the Dharwar craton towards west and the EGB towards the east. The rocks of the NKSB have

undergone polyphase deformation and show a prominent NNE-SSW to NE-SW fabric in the northern parts (Sarvothaman, 1995). The NKSB is composed of amphibolites, granite gneisses and metasediments including banded iron formations and unique Archaean Anorthosite Layered Complex at Chimalpahad. Similar lithological associations elsewhere have been attributed to a shallow-marine platform-type setting (Arndt et al., 1997). The Chimalpahad Layered Anorthosite Complex (CLAC; $17^{o}18^{1}$ and $17^{o}\ 34^{1}$ N; $80^{o}23^{1}$ and $80^{o}35^{1}$ E) is an arcuate meta-igneous body with a surface area > 200 sq.km. The CLAC is one of the largest metamorphosed Archaean Layered Anorthosite Complexes in India. The CLAC occurs as a conformable sill-like body within schistose and gneissose rocks of NKSB. The complex is cut across by mafic sills and dykes.

REVIEW OF LITERATURE

Most of the Archaean Layered Anorthosite Complexes are 2.8 to 3.2 Ga and they are usually sheet-like and are intruded into rocks at shallow depths. They are usually <1 km thick but can be several km long. The complexes are composed of ultramafic rocks, anorthosites, and leucogabbronorites. Cumulate textures predominate. Because the rocks are *cumulate* the bulk chemistry of the lithounits is not representative of the original magmatic liquid. The original liquid is inferred to be an Fe-rich basaltic magma. The parental Fe-rich basaltic magma would have crystallized olivine and pyroxene which settled out. The later magma would crystallize plagioclase.

Fiskenaenset (Greenland), Messina (South Africa), Bad Vermilion (Canada) and Shawmere (Canada) Archaean Anorthosite Complexes are some of the well studied complexes in the world. Among the Archaean anorthosites, the largest recognized example (~2250 km^2) is the Windimurra Complex in the Yilgarn Craton of Western Australia (Mathison & Ahmat 1996), but most other occurrences are far smaller (<500 km^2, and typically ~10 km^2). Perhaps the best known examples occur in West Greenland, and include the ~500 km^2 Fiskenæsset Complex, which is exceptionally well preserved (*e.g.*, Myers 1985).

The Archaean anorthosites are associated with mafic intrusive and extrusive rocks (Ashwal 1993, Ashwal & Myers 1995). Megacrystic plagioclase, which is often high-calcic set in a mafic ground-mass defines the characteristic texture of these rocks. Metamorphic grade among the ~70 known Archaean anorthosites varies between sub-greenschist and granulite facies conditions; however, magmatic textures and structures are not uncommon among the Archaean anorthosites.

The Archaean anorthosites are considered to represent eroded sub-volcanic magma chambers which fed the erupted mafic melts. Proposed parental magmas to the Archaean anorthosites range from Fe-rich tholeiitic basalt to komatiite magmas (Phinney & Morrison 1990). One possible reason for the high calcic nature plagioclase in these anorthosites could be due to high pH_2O conditions as documented experimentally (Sisson & Grove 1993). One possible origin for the Archaean anorthosites is in an island arc or continental arc-type setting (Ashwal, 1993).Similar Phanerozoic analogs are suggested for some arc-related gabbro-anorthosites from Sweden (Claeson & Meurer 2004).

OBJECTIVE OF RESEARCH

The objective of the present study is decipher the mantle source composition, composition of parental liquids, and parental magma evolution within the magma chamber to form the ultramafic, mafic and anorthosite cumulates, tectonic environment of original emplacement of Chimalpahad Archaean Layered Anorthosite Complex. This will help in deciphering the nature of mantle source composition, sub-volcanic magma chamber processes and evaluate the certainty of plate-like processes in Archaean times.

METHODOLOGY TO BE ADOPTED

Detailed filed studies including sampling of all the lithounits, comprehensive petrographic studies and geochemical and mineral-chemical analyses for major, trace and rare earth elements for a large number of samples will be the methodology we adopt to achieve the objectives of the study.

Field survey and sample collection

Detailed filed surveys will be conducted in and around Chimalpahad Anorthosite body and surrounding areas. A large number of fresh and *in situ* samples will be collected. All the required field parameters will be recorded at the sites themselves. Field photographs will be taken to record the important field features.

Analyses of samples

Thin sections of rocks will be made and petrographic studies will be carried out to understand mineralogy and textures. Mineral-chemical analyses will be carried out to understand the patterns of magma evolution and conditions of magma crystallization and cooling. Geochemical analysis of representative rock samples will be carried out in the Geochemical Laboratories of National Geophysical Research Institute (NGRI), Hyderabad to understand the magma chamber processes, estimation of parental liquid composition and consequently the mantle sources.

IMPORTANCE OF STUDY

International Status

A major problem concerning the genesis of Archaean Layered Anorthosite Complexes is the determination of the parental liquid composition subsequently the mantle sources and tectonic environment of emplacement. Additionally, restriction of these complexes to Archaean and high-An content of plagioclase illustrate the influence of source, process and conditions on the origin of these temporally and spatially restricted complexes.

An oceanic tectonic setting is proposed for the Archaean anorthosites. Therefore, their present occurrence within the continents may suggest closure of ocean basins and accretion to the continental masses, processes similar to the modern ophiolite formation. In that sense, the Archaean anorthosites represent sites of ancient ocean closures – the sutures. However, there are marked differences between the anorthosites present within the ophiolites and the Archaean anorthosites suggesting fundamental differences in the Archaean and modern plate-like processes.

In summary, primordial Archaean layered anorthosites have a distinct textural and compositional nature and are restricted in time and space. High An (An > 80) megacrystic anorthosites are found only the Archaean, where they are associated with mafic-ultramafic volcanic rocks of greenstone belts. It is suggested that they may have formed by accumulation of An-rich plagioclase from mafic to ultramafic magmas. It has been argued that high H_2O content of parental melts may explain the calcic composition of plagioclase, and the temporality might be linked to that of komatiitic magmatism.

National status

Excellent, albeit limited geological and petrological aspects on the Archaean anorthosites of India are available (for a review see Leelanandam, 1987). Three major Archaean Layered Anorthosite Complexes in India include the Sittampundi (Tamilnadu), Holenarsipur (Karnataka) and Chimalpahad (Andhra Pradesh) complexes. Earlier studies in these complexes concentrated on the mineral-chemical variation, metamorphic grade and chromite-silicate relationships. Sm-Nd age data is also available for these complexes. Recent studies suggest supra-subduction setting for Sittampundi and Chimalpahad anorthosites. However, systematic geochemical studies on the complexes to decipher nature of mantle sources, parental liquid compositions, magma chamber processes, and original emplacement tectonic environment are lacking. The proposed work in the Ph.D. attempts to fill this gap in our knowledge by carrying out detailed geochemical and mineral-chemical studies on the Chimalpahad Anorthosite Complex.

Significance of the study

The Chimalpahad Anorthosite body is a rare Archaean anorthosite with the Schist belt probably one of its kind in India. Delineation of origin and tectonic environment of its emplacement will be a significant contribution to our understanding Archaean mantle sources and tectonics.

PROPOSED WORK PLAN

First Year:

Literature Survey

A review of published literature on Indian and global Archaean anorthosites will be carried out; unpublished material from Geological Survey of India (GSI) and other institutions specific to study area will also be collected

Field work and sample collection

Detailed field surveys will be conducted in and around Chimalpahad Archaean Layered Anorthosite Complex for the collection of rock samples from all the exposed lithounits. Structural data will be collected on both the intrusive and the enclosing rocks.

Second Year:

Petrographic, Mineral-chemical and geochemical analysis of mineral and rock samples

Petrographic studies and mineral-chemical and geochemical analyses of representative rocks and constituent minerals will be carried out in the Geochemical Laboratories of National Geophysical Research Institute (NGRI), Hyderabad.

Third Year:

1. **Interpretation of Data:** Field, petrographic and geochemical data will be synthesized and interpreted employing of the aforesaid tools.
2. **Writing and Submission of Thesis:** The thesis will be written after the interpretation of data and achievement of objectives and will be submitted at the end of third year.
3. **Presentation in Seminars** at national and international level.
4. **Publication of research papers** in National and International Journals.

REFERENCES

ASHWAL, L.D. (2010) The temporality of anorthosites. The Canadian Mineralogist v. 48, pp. 711-728.

ASHWAL, L.D. (1993) Anorthosites. Springer-Verlag, Berlin, 421 pp.

ASHWAL, L.D. & MYERS, J.S. (1995): Archean anorthosites. In Archean Crustal Evolution (K.D. Condie, ed.). Elsevier, Amsterdam, The Netherlands (305-345).

ASHWAL, L.D., MORRISON, D.A., PHINNEY, W.C. & WOOD, J. (1983): Origin of Archean anorthosites: evidence from the Bad Vermilion Lake anorthosite complex, Ontario. Contrib. Mineral. Petrol. 82, 259-273.

BEARD, J.S. (1986): Characteristic mineralogy of arc-related cumulate gabbros: implications for the tectonic setting of gabbroic plutons and for andesite genesis. Geology 14, 848-851.

BHASKAR RAO, Y., KUMAR, A., VREVSKY, A.B., SRINIVASAN, R. & ANANTHA IYER, G.V. (2000): Sm–Nd ages of two meta-anorthosite complexes around Holenarsipur: constraints on the antiquity of Archean supracrustal rocks of the Dharwar Craton. Proc. Indian Acad. Sci., Earth and Planetary Sci. 109, 57-65.

BHASKAR RAO, Y.J., CHETTY, T.R.K., JANARDHAN, A.S. & GOPALAN, K. (1996) Sm–Nd and Rb–Sr ages and P–T history of the Archean Sittampundi and Bhavani layered meta-anorthosite complexes in the Cauvery shear zone, South India: evidence for Neoproterozoic reworking of Archean crust. Contrib. Mineral. Petrol. 125, 237-250.

BOWEN, N.L. (1917): The problem of the anorthosites. J. Geol. 25, 209-243.

BURKE, K. & DEWEY, J.F. (1973) An Outline of Precambrian Plate Development. Academic Press, London, pp. 1035-1045.

CAWOOD, P. A., KRONER, A. & PISAREVSKY, S. (2006) Precambrian plate tectonics: criteria and evidence. GSA Today, v. 16, pp. 4-11.

CLAESON, D.T. & MEURER, W.P. (2004): Fractional crystallization of hydrous basalt in "arc-type" magmas and the formation of amphibole bearing gabbro cumulates. Contrib. Mineral. Petrol. 147, 288-304.

DeBARI, S.M. (1997) Evolution of magmas in continental and oceanic arcs: the role of the lower crust. Can. Mineral., v. 35, pp. 501-519.

DHARMA RAO, C.V., WINDLEY, B.F. & CHOUDHARY, A.K. (2011) The Chimalpahad anorthosite Complex and associated basaltic amphibolites, Nellore Schist Belt, India: Magma chamber and roof of a Proterozoic island arc. Journal of Asian Earth Sciences, v. 40 pp. 1027–1043.

FERMOR, L.L. (1936) An attempt at the correlation of ancient schistose formations of peninsular India. Mem. Geol. Surv. India 70, pp. 1-51.

HAMILTON, W. (1981): Crustal evolution by arc magmatism. In the Origin and Evolution of the Earth's Continental Crust (S. Moorbath & B.F. Windley, eds.). Phil. Trans., R. Soc. London A 301, 279-291.

LEELANANDAM, C. (1987) Archaean anorthosite complexes: An overview. In Saha, A.K. (Ed.) Geological Evolution of Peninsular India - Petrological and Structural Aspects. Hindustan Publishing Corporation (Delhi), pp. 108-116.

LEELANANDAM, C. & NARSIMHA REDDY, M. (1983) Plagioclase feldspars and hornblendes from the Chimalpahad complex, Andhra Pradesh, India. Neues Jahrbuch fur Mineralogie Abhandlungen, v. 148, pp. 200-222.

LEELANANDAM, C. & NARSIMHA REDDY, M. (1985) Petrology of the Chimalpahad anorthosite complex, Andhra Pradesh, India. Neues Jahrbuch fur Mineralogie Abhandlungen, v. 153, pp. 91-119.

MYERS, J.S. (1985): Stratigraphy and structure of the Fiskenæsset Complex, southern West Greenland. Grønlands Geol. Undersokelse Bull. 150.

NARSIMHA REDDY, M. AND LEELANANDAM, C. (1998) Textural and structural features of the Chimalpahad Layered Complex, Andhra Pradesh, India. Int. Seminar on Precambrian Crust in Eastern and Central India (UNESCO-IUGS-IGCP-368), Bhubaneswar (abstracts, pp. 93-95).

NARSIMHA REDDY, M. AND LEELANANDAM, C. (2004) Magmatic and tectonic structures from the Chimalpahad Layered Complex, Andhra Pradesh, India. Gondwana Res., v. 7, pp. 887-896.

PHINNEY, W.C. & MORRISON, D.A. (1990): Partition coefficients for calcic plagioclase: implications for Archean anorthosites. Geochim. Cosmochim. Acta 54, 1639-1654.

PHINNEY, W.C. (1982): Petrogenesis of Archean anorthosites. In Workshop on Magmatic Processes of Early Planetary Crusts: Magma Oceans and Stratiform Layered Intrusions (D. Walker & I.S. McCallum, eds.). Lunar and Planetary Inst., Tech. Rep. 82–01, 121-124.

RADHAKRISHNA, B.P. & NAQVI, S.M. (1986) Precambrian continental crust of India and its evolution. Jour. Geol., v. 94, pp. 145-166.

RAMAKRISHNAN, M. & VAIDYANADHAN, R. (2008) Geology of India. Vol, 1, Geological Society of India, Bangalore, 994 p.

RAMAKRISHNAN, M., NANDA, J.K. & AUGUSTINE, P.F. (1998) Geological evolution of the Proterozoic Eastern Ghats Mobile Belt. Geol. Surv. Spec. Publ., 44, pp. 1-21.

SARVOTHAMAN, H. (1996) Spatial association of Precambrian aluminous – and Fe-tholeiites: evidence from anorthosite-amphibolite association in Khammam schist belt, Andhra Pradesh. Geol. Surv. India Spec. Publ. No. 40, pp. 43-58.

SISSON, T.W. & GROVE, T.L. (1993): Temperatures and H2O contents of low MgO high-alumina basalts. Contrib. Mineral. Petrol. 113, 167-184.

VIJAYA KUMAR, K., NARASIMHA REDDY, M. & LEELANANDAM, C. (2006) Dynamic melting of the Precambrian mantle: evidence from rare earth elements of the amphibolites from the Nellore-Khammam schist belt, south India. Contrib. Mineral. Petrol., v. 152, pp. 243-256.

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